STRUCTURAL MATERIALS FOR ADS

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The structural materials for use in Accelerator Driven Systems must be able to withstand high doses in a high energy (> 20 MeV) proton and neutron flux at various temperatures from 200 to 600ºC. Irradiation of materials in such a high energy spectra not only produces displacement damage in the lattice but also produces hydrogen and helium from spallation. This damage can result in deleterious effects on mechanical properties.
To qualify materials for use in the Advanced Fuel Cycle Initiative (AFCI), an aggressive program has been constructed to measure materials properties after irradiation in a high energy proton beam and to construct the Materials Test Station (MTS) at Los Alamos to irradiate materials in prototypic AFCI fluxes and irradiation temperatures and test target concepts. Recent results of high temperature compression, 3 pt. Bend, tensile, shear punch testing of Mod 9Cr-1Mo, 316L, tungsten and tantalum will be presented at testing temperatures from room temperature to 500ºC. In addition, plans for future testing and construction of the MTS will be discussed.
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1. Introduction

Recently, many programs have shown a need for data on the effects of high energy protons and spallation neutrons on the properties of materials. In an attempt to satisfy these needs, irradiation programs were undertaken at the Los Alamos Neutron Science Center's (LANSCE) 800 MeV proton accelerator at Los Alamos National Laboratory (LANL) and the ~570 MeV proton accelerator at the Paul Scherrer Institut (PSI). Irradiations at LANL were performed using the Los Alamos Radiation Effects Facility (LASREF) which has been inactive since March 1999. Eight inserts containing mechanical test specimens and experimental capsules were designed and irradiated for 6 months during a period from September 1996 to July 1997.[1] Then five new inserts were irradiated from October 1998 to December 1998. During this irradiation campaign approximately 5,000 specimens were irradiated. The maximum fluence obtained was 3-4 x 10^{25} p/m^2 which in the steels was ~ 12 dpa and 24 dpa in tungsten. The irradiation temperature ranged from 50 to 200ºC in the steels and up to 270ºC in the tungsten. Materials irradiated included structural materials

(304L/316L stainless steel, Inconel 718 in the precipitation hardened condition, Mod9Cr-1Mo, F82H, Al6061-T6, Al5052-O), target materials (tungsten, tantalum and Ta-10W) and components (clad tungsten neutron source, lead blanket, tungsten decay heat measurement insert, In situ corrosion measurement insert).

Concurrently, in 1996 an irradiation program was initiated at PSI. This irradiation uses the target at the end of the ~570 MeV, 850□A SINQ accelerator and is called the SINQ Target Irradiation Program (STIP)[2]. The first irradiation was carried out from July 1998 to December 1999 (STIP-1). A maximum fluence of 3.2 x 10^{25} p/m^2 was achieved equivalent to ~12 dpa in steel and the irradiation temperature ranged from 70 to 350ºC. Numerous different alloys were irradiated during this irradiation. Those tested at LANL were rods of Mod9Cr-1Mo and 316L. A second irradiation, STIP-II, finished at the end of 2002. Specimens are presently being sent to laboratories for analysis. A third irradiation, STIP III is in progress and STIP IV is scheduled to start in 2005.

2. Highlights of Results

The LANSCE irradiations using the 800 MeV accelerator yielded results in areas of corrosion of materials in a proton beam, solid target neutron source design and experience and the effects of high energy proton fluence on the mechanical properties of materials. In the first 2 months of the 1996-1997 irradiation, a large among of tungsten was found in the cooling water for a bare tungsten rod neutron source.[3] This insert was removed and diametral measurements confirmed a corrosion rate of ~1 mm/year in the proton beam. Another insert was specifically designed to measure corrosion in situ while the proton beam was running. Data from corrosion testing using this insert proved that a much lower corrosion rate was observed for 316L stainless steel and Inconel 718 (~5µm/year).[4] In addition, a slip clad tungsten neutron source was designed and irradiated successfully in the 800 MeV, 1 mA proton beam for 6 months of operation.[5]

Numerous mechanical test specimens were irradiated in the 800 MeV proton beam to a maximum dose of 12 dpa at irradiation temperatures of 50-200ºC. Numerous results were obtained on the effects of high energy protons on the mechanical properties of materials.[6] One specific highlight showed that when comparing the tensile properties measured on 316L stainless steel after irradiation in a proton beam to those measured after irradiation in a fission neutron flux, a drop in ductility (strain-to-necking) is observed ~ 10 dpa sooner than observed under the same irradiation and test temperatures in a fission neutron flux.[7]

Numerous results on the effects of high energy proton irradiation on the mechanical properties of materials have also been published from data measured on specimens irradiated in STIP I[8]. The major difference from the STIP irradiations versus the LANSCE irradiation is that the test temperature is 100-200ºC higher for materials irradiated in the STIP irradiations. Recently specimens were tested at LANL of 316L and Mod-9Cr-1Mo after being irradiated in the STIP I irradiation at 225 to 300ºC. Specimens were irradiated in rod form to a maximum dose of 9.8 dpa. To obtain mechanical properties in 3 pt. Bending, specimens were sliced from the rods in the hot cells to obtain rectangular specimens with the dimensions of 2mm x8mm x0.25 mm. The surfaces of these specimens were ground with 800 grit paper before testing. The stress vs. strain in the outer fiber is plotted for 316L tested at 25-350ºC in Fig. 1A and Mod 9Cr-1Mo tested at 25-500ºC in Fig. 1B. These curves show two tests plotted for each condition. Very good agreement is observed for all curves. The data show the significant effect of irradiation on increasing bending yield stress as well as the effect of increasing temperature on decreasing bending yield stress. Increasing temperature appears to have a larger effect on the bend yield stress for the irradiated specimens as some recovery of the irradiated microstructure occurs during testing at higher temperatures. Photos of the bent surfaces are shown in Fig. 2(A+B). These show more localized deformation in the irradiated specimens. This testing is in progress and more detailed results will be presented at a later data.

3. Future Near Term Testing

Future plans at the LANL hot cells will involve testing of ferritic/martensitic alloys after irradiation in STIP II, III and IV irradiations at irradiation and test temperatures of 400 to 700C. In addition, specimens irradiated in a fast neutron flux to high dose are also of importance to the Advanced Fuel Cycle Initiative and Generation IV Reactor Programs. It was recently learned that approximately 2000 previously untested specimens are available irradiated in the Fast Flux Test Facility (FFTF) in the Liquid Metal Fast Breeder Reactor (LMFBR) MOTA-1 and Fusion MOTA-2 series of experiments. Many of these specimens were irradiated to 100 to 200 dpa at temperature from 400 to 700ºC. Materials available are heats of HT-9, MA-957 and 9Cr-1Mo in the form of pressurized tubes, tensile specimens, compact tension and transmission electron microscopy (TEM) disks.

4. New Test Station Proposal

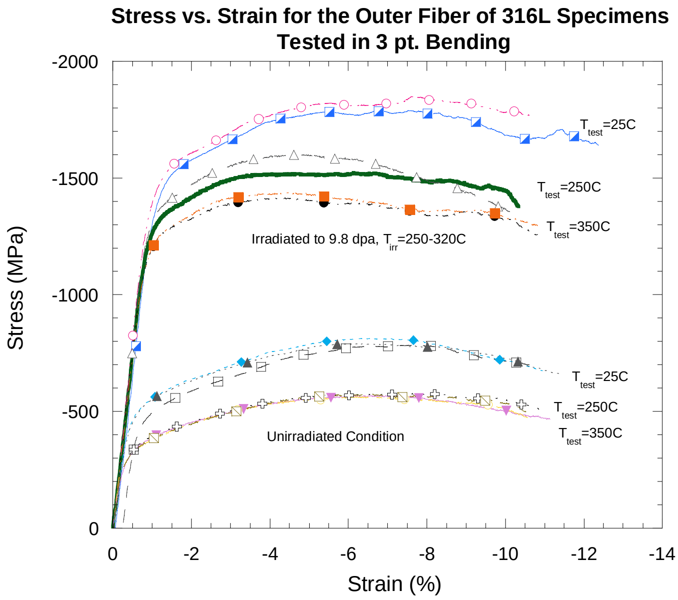
To advance the maturity of the technology needed to prove the feasibility and performance of the Advanced Fuel Cycle Initiative and Generation-IV systems, the effect of irradiation and corrosion of materials and fuels needs to be addressed. The US is fortunate to have the world class LANSCE accelerator facility at Los Alamos. By adding a Materials Test Station (MTS) in an existing experimental hall, the US would have a broad-spectrum irradiation test facility for performing the needed research.

LANSCE-MTS consists of the existing accelerator, a spallation target, a reflector and sample irradiation locations. The spallation target, reflector and sample irradiation locations are all contained in a vacuum vessel that are positioned at the end of the 800 MeV LANSCE accelerator as shown in Figure 3.

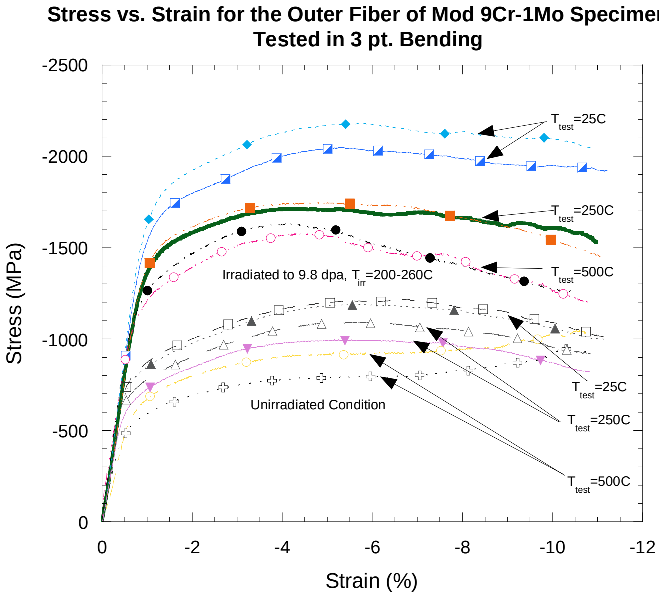
The LANSCE/MTS attributes include:

- Neutron spectrum similar to that of a fast reactor (necessary for actinide transmutation),
- neutron intensity up to $1x10^{15}$ $n/cm^2/s$,
- the flexibility for testing of materials in different coolants and temperatures simultaneously in closed loops,
- transient testing and run to failure, and
- the ability to achieve high helium generation in structural materials.

Because the MTS is a small upgrade to an existing facility, it can be brought on line quickly and at a modest cost. The installation is estimated to cost $20M and take 3 years. Operation costs are estimated to be approximately $3M per year there after.

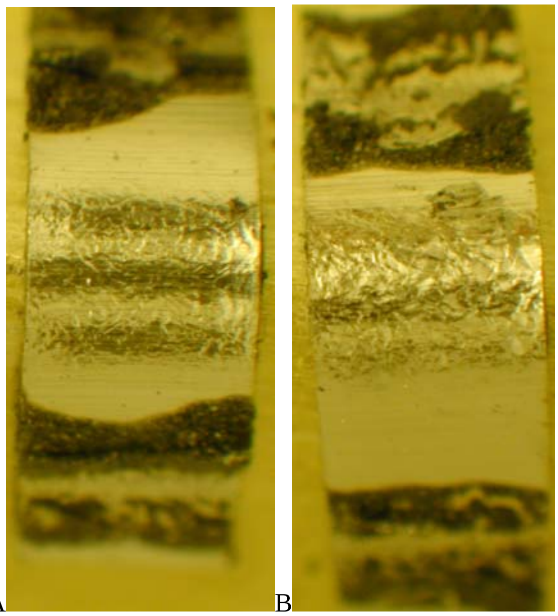


A.



B.

Figure 1 Plots of Stress vs. Strain for the outer fiber of 3 pt. Bend specimens (A. 316L stainless steel, B. Mod 9Cr-1Mo) before and after irradiation in a high energy proton beam. Specimens were tested at 25, 250, 350 and 500ºC.



A B

Figure 2 Optical photos showing outer surface of (A) Unirradiated and (B) Irradiated (9.8 dpa) Mod 9Cr-1Mo specimens after bending to ~10% strain in the outer fiber. Width of specimens is 2 mm (approximately 20X magnification).

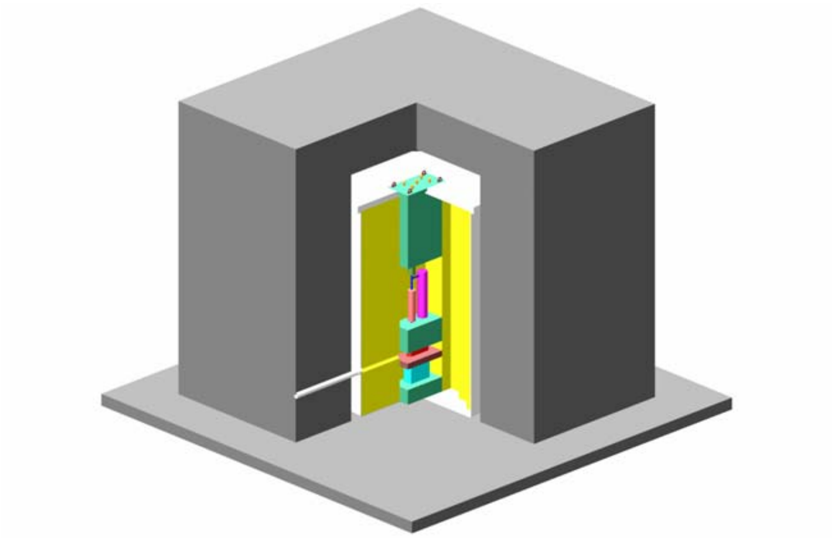


Figure 3. MTS Vacuum Tank, Shield and Target Assembly Shown Nested Within it's Shielding. The Vacuum Tank is 13 feet in Diameter

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